TMO TECHNOLOGY DEVELOPMENT PLAN

Ka-Band Experiments Work Area

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OBJECTIVE:
The objective of this work area is to achieve a four fold increase in DSN capacity with no new antennas by establishing the viability of Ka-Band for deep space missions through experiments with spacecraft and radio sources and quantifying the end-to-end performance advantage of Ka-Band relative to X-Band.

GOALS and SIGNIFICANCE:
The goals of this work area are: to implement low-cost Ka-Band (32 GHz) downlink on MGS and DS-1, to obtain on a best efforts basis X and Ka-Band downlink from SURFSAT-1, to receive and track the Ka-Band and X-Band links at DSS-13 and DSS-25 (for DS-1 only), to evaluate G/T advantage of Ka-Band relative to X-Band for DSN ground stations using both spacecraft and natural radio sources, to characterize the statistical effects of atmosphere at Ka-Band and quantify temporal variability of the Ka-Band link performance due to weather effects, and to quantify the incremental Ka-Band BWG performance improvements.

MGS has the first fully functional Ka-Band downlink on a planetary mission and DS-1 is the first planetary mission to carry an independent Ka-Band transponder. By using the downlink signal from these two spacecraft it is possible to compare X-Band and Ka-Band link performances over the same path and measure critical Ka-Band link parameters as they change with time, weather, elevation and spacecraft effects. This will identify what link elements need to be and can be changed to improve the performance of the Ka-Band link and provide checks on the expected improvements. The data could be further augmented by previously acquired data from SURFSAT-1 at both X and Ka-Bands. This knowledge is then transferred to TMOD to allow future missions to consider the use of Ka-Band in their planning stage.

PRODUCTS:
The products of this work area are: MGS Ka-Band downlink, DS-1 Ka-Band downlink, SURFSAT-1 Ka-Band downlink on a best efforts basis, Ka-Band data acquisition and analysis for MGS, DS-1 and, if possible SURFSAT-1, Ka-Band Antenna Performance experiment (KaAP) efficiency and G/T vs. elevation angle measurements and calculations and atmospheric noise statistics.

DESCRIPTION:
As NASA moves towards the era of “faster-cheaper-better” spacecraft, it is expected that the number of planetary missions which DSN tracks will increase. In addition, it is expected that these spacecraft will be smaller and consume less power than their predecessors. Hence it is necessary both to increase the capacity of the DSN to track mission and to utilize the power resources on the spacecraft more efficiently. Analysis shows that by using Ka-Band instead of X-Band, between four to six times the current capacity of the DSN could be achieved. The switch to Ka-Band also allows the use of existing tracking apparatus at the DSN communication complexes with minor changes to equipment and operating procedures.

In order to validate the results of this analysis it is necessary to demonstrate the performance of the downlink from planetary missions. In addition, it is necessary to characterize the performance of both spacecraft and ground equipment under various conditions in order to provide a road map for future implementation of Ka-Band in the DSN and to identify the areas in which the best performance improvement to cost ratio could be achieved.

The KaBLE work unit will demonstrate the Ka-Band link performance for DS-1 and MGS spacecrafts and if possible, SURFSAT-1. In addition it will result in characterization of the spacecraft and provide a signal for characterization of the ground equipment. Performance of the link will be measured in terms of telemetry, radio science open loop recordings, ranging and Doppler performance.

Furthermore, the effects of different ground system and spacecraft configurations and weather effects on these measurements will be characterized and the areas of improvement will be identified.

Characterization of the BWG antenna performance at Ka-Band is done in the Ka-Band Antenna Performance experiment (KaAP) work unit. In this work unit, the G/T and efficiency of DSS-13 will be measured through the use of natural radio sources as well as spacecraft signals. Furthermore, this work unit shall provide statistical measurements of the atmospheric noise measurements, techniques for gathering of such data and comparison with Water Vapor Radiometer (WVR) measurements. This will result in further understanding of the Ka-Band link.

By thus characterizing the link performance and ground equipment performance, a clear picture of capabilities of the Ka-Band downlink will emerge and its advantages over the X-Band link will be demonstrated.

DELIVERABLES:
Track MGS/KaBLE through aerobraking and mapping consistent with MGS project constraints. Evaluate Ka-Band vs. X-Band performance for MGS downlink during solar conjunction in terms of amplitude and phase scintillation, Doppler, ranging and telemetry. Analysis of the KaBLE data in monthly and quarterly reports and produce TDA progress reports accordingly. Plan for DS-1/KaBLE activities and initiate data acquisition after launch. Evaluation of DSS-13, DSS-25 and DSS-14 with the array feed Ka-Band performance. Monthly KaAP boresight observation of natural radio sources at X-Band and Ka-Band to characterize antenna performance and Ka-Band advantage over X-Band. TDA Progress Report on comparison of tip curve atmospheric noise temperatures measured during SURFSAT-1 tracks and those obtained from WVR. TDA Progress Report on SURFSAT-1 link advantage and/or technical challenges in determining spacecraft orientation from the data.

RESOURCE REQUIREMENTS BY WORK UNIT:

	JPL Account #	FY 98	FY 99	FY 00
KaBLE	462-42260	250	170	100
KaAP	462-42217	152	148	
Total		402	318	100
Total Workforce		2	1.8	0.5

TMO TECHNOLOGY TASK DESCRIPTION

TITLE: Mars Global Surveyor Ka-Band Link Experiment (MGS/KaBLE-II)	
WORK UNIT IN WHICH FUNDED: KaBLE 462-42260	
WORK AREA: Ka-Band Experiments	

BRIEF TECHNICAL SUMMARY:

The objective is to evaluate space-to-ground telecommunications using Ka-Band (32 GHz) and X-band (8.4 GHz) downlinks from Mars Global Surveyor (MGS), DS-1, and, if possible, SURFSAT-1 to the Deep Space Network (DSN) Research and Development station, DSS-13. Observations will be collected through the duration of the MGS and DS-1 missions to establish credible performance data for mission planning.

JUSTIFICATION AND BENEFITS:

The data return projected for Ka-band is 4 times (6 dB) more than with X-Band. That would enable the existing DSN to support 4 times as many missions without the expense of adding 3 times as many antennas (at $30 million each). Alternatively, for the same data return as at X-band, this 6 dB advantage could reduce mission cost by either reducing the size of spacecraft antennas, transmitters or DSN coverage.

Because spacecraft antenna gain is canceled by space loss, the advantage of Ka-band over X-band can be viewed as stemming from DSN antenna gain-to-temperature ratio, G/T. In atmosphere, at Ka-band the DSN G/T is 6 to 7 dB greater than at X-band (90% of the time). However, link variations with weather, elevation and pointing are also much larger at Ka-band. To determine if Ka-band will be viable operationally, the frequency of occurrence and magnitude of such variations must be assessed. This is most directly and accurately done by coherently tracking a planetary spacecraft in both frequency bands simultaneously, and over a statistically significant time period.

APPROACH AND PLAN:

Launched on November, 7 1996, MGS has a 1 watt Ka-Band downlink with an EIRP of 76 dBm, along with the primary 25 watt X-band (8.42 GHz) downlink with EIRP of 82 dBm. Both are emitted from the 1.5 m high gain antenna (HGA) and have been simultaneously tracked at DSS 13 on a regular basis since January 17, 1997. DS-1 will be launched on July 1, 1998. DS-1 carries a 12W X-Band transponder with a primary 12W X-Band downlink with an EIRP of 63dBm and a 2.5W Ka-Band downlink with an EIRP of 59dBm. It is expected that both downlinks for DS-1 will be simultaneously tracked with either DSS-13 or DSS-25.

To obtain a statistically significant data base, this task will continue to track both links for the duration of the MGS mission into the year 2000, including measurement of space plasma effects during superior conjunction in May 1998. Similarly, it is expected that this task will track DS-1 as well. Observations will be analyzed and reported informally in monthly and quarterly progress reports. Formal summaries will be published as DSN progress reports or open literature articles, as appropriate. Operations will be coordinated with the MSOP project, DS-1 project, DSS 13 and DSN. At least two passes per week will be conducted for MGS at DSS 13 whenever Ka-band transmission is permitted by the project (Ka-band transmissions will be halted for spacecraft safety, or low energy margin). For DS-1 it is expected to perform at least two tracks a month at either DSS-13 or DSS-25. For MGS measurements will primarily be 1 sec samples of carrier power to noise ratio, its phase and frequency. Dual frequency X/Ka band ranging and telemetry tests will be conducted when MGS operating modes permit and SPC-10 resources are available. Since DS-1 has a more stable Ka-Band transponder, the tests performed using DS-1 will emphasize measuring the performance of the telemetry. Furthermore, whenever DSS-25 is used for tracking the DS-1 ranging and Doppler will be available at SPC-10 for both X and Ka downlinks whenever Ka-Band downlink is active.

DELIVERABLES:

FY98 Q1: 3 Monthly and 1 quarterly informal reports

FY98 Q2: 3 Monthly and 1 quarterly informal reports + 1 TDA progress report article

FY98 Q3: 3 Monthly and 1 quarterly informal reports

FY98 Q4:3 Monthly and 1 quarterly informal reports + 1 TDA progress report or open literature article

RESOURCE REQUIREMENTS:

	Prior Year(s)	FY98	FY99	FY00	Total at Completion
Funding ($K)		250	170	100	520
Workforce (WY)		1	0.8	0.5	2.3
Co-funding ($K)					
Projected Savings ($K)					

TMO TECHNOLOGY TASK DESCRIPTION

TITLE: Ka-Band Experiment Analysis	
WORK UNIT IN WHICH FUNDED: KaAP 462-42217	
WORK AREA: Ka-Band Experiments	

BRIEF TECHNICAL SUMMARY:
Ka-band (32.0 GHz) communications offer significant performance advantages over X-band (8.4 GHz) for future mission planners. Since the ratio of the gains are proportional to the ratio of the frequencies squared, one might expect about a 14.5 factor (11.6 dB) increase in gain at Ka-band. However, because of the different efficiencies of the ground antenna at the two frequencies and the higher atmospheric noise temperature at Ka-band, this is gain reduced to between 6 to 8 dB for the ground station. More accurate characterization of this Ka-band ground system advantage and of its temporal variability due to weather effects is required to allow future mission planners to assess the advantage of moving telemetry to Ka-band. The Ka-band experiments at the 34-m beam-waveguide-antenna (BWG) utilize dual-frequency observations of natural calibrator radio sources or spacecraft signals (SURFSAT-1 and MGS KaBLE-II and DS-1) at X-band (8.4 GHz) and Ka-band (32.0 GHz). The G/T at each frequency provides an estimate of the performance of the antenna and equipment. By comparing the G/T at Ka-band with that at X-band, one obtains an estimate of the measured ground system advantage of Ka-band relative to X-band which can then be compared with predicted values. This work unit thus serves to benchmark continuing improvement in Ka-band ground system performance, and can also identify degradation in equipment that results in a reduction of a receiving system's G/T. Another purpose of the experiments is to characterize the atmospheric noise temperature statistics at both bands and determine their cumulative distributions. Such distributions are essential for developing robust, efficient telecommunication strategies at Ka-band.

JUSTIFICATION AND BENEFITS:
The expected 6 to 8 dB ground system advantage of Ka-band relative to X-band can allow flight projects to reduce costs of future space missions. Spacecraft equipment can be developed for Ka-band which may be smaller (less mass and/or volume) and consume less power. Future space missions may also have radio science experiments where the unmodulated carrier is the main data type and the knowledge gained from these efforts will contribute to a better understanding of that data type at Ka-band.

The justification and benefit of performing such experiments is that the end-to-end ground system advantage of Ka-band relative to X-band is quantified, the improved performance due to incremental improvements of the station (main reflector, sub-reflector and mirror alignments, upgraded equipment, etc.) can be quantified, operational strategies for BWG antennas can be demonstrated, and knowledge gained can be transferred to future flight projects to enable better Ka-band consideration or planning.

APPROACH AND PLAN:
For the Ka-Band Antenna Performance calibration with natural radio sources, the approach is to conduct periodic (twice monthly) experiments of 16 to 24 hours duration of boresight observations of natural calibrator radio sources (sources whose flux strengths do not exhibit significant temporal variation) at both Ka-band and X-band. The boresight observations involve moving the antenna beam through the source in two orthogonal directions while taking operating system noise temperature measurements. By fitting these measurements to a Gaussian model, the peak temperature of the source can be estimated. From the peak temperature, the efficiency can then be determined for that observation. Many observations are spread over elevation angle, allowing the efficiency versus elevation angle curve to be measured. The boresight observations of different sources are interleaved in time along with radiometer calibrations which allow calibration of system gain variation and determination of system linearity. In addition to these observations, tipping curves are also performed to allow determination of 1) the atmospheric loss factors used to refer the efficiency calculations to zero atmosphere and 2) the atmospheric noise temperatures whose statistics can then be characterized

and correlated with those determined from ancillary WVR and weather data. The antenna efficiency data will be used to calibrate DS-1, MGS/KaBLE-II and SURFSAT-1 ground station model, and provide performance estimates over the full range of elevation angles.

SURFSAT-1 data were acquired for a total of 418 tracks conducted between launch (November 5, 1995) and December 1996, observing the Ka-band and X-band signals emitted from the spacecraft. The received Doppler frequencies and signal levels were collected in a large database. These data indicate that SURFSAT-1 was not in its nominal expected orientation, and that the orientation appeared to change significantly from pass to pass (a challenge which was not previously anticipated or considered). Therefore, the resulting advantage of Ka-band relative to X-band can not yet be determined from the data. Analysis software has already been written and tested which can process the data from one or multiple passes, and fit for (or force) different orientation models yielding residual signal strengths. It is anticipated that additional analysis (and model development) will be required in order to attempt to decipher the satellite's dynamic motion before meaningful characterizations can be realized. Further data analysis will continue on best effort basis to study and implement strategies to decipher SURFSAT-1's orientation from the collected data. A TDA progress report on the SURFSAT-1 data analysis efforts and/or results is expected to be issued.

The Total Power Radiometer (TPR) data (operating system noise temperatures) which have been recorded during the SURFSAT tracks have been processed to produce atmospheric noise temperatures at zenith using a tipping curve algorithm developed for natural radio source calibrations of the antenna. The resulting atmospheric noise temperatures have been compared with values estimated from 32 GHz weather model forecasts based on surface measurements and 31.4 GHz sky brightness temperatures measured by Water Vapor Radiometers (WVR) which reside on-site at DSS-13. This work will continue into fiscal year FY98 which will include 1) installing the algorithm in the KaBLE-II processing software to produce similar statistics from the MGS/KaBLE-II and DS-1 TPR data, 2) correlate atmospheric temperature fluctuations (from tip curve post-fit residuals) with signal level fluctuations and received frequency residuals, and 3) derive antenna temperature versus elevation angle curves from the Surfsat-1 X-band TPR data using the Ka-band TPR data to constrain the X-band atmosphere model, separately for northern (presence of a mountain) and southern horizons.

The DSS-13 TPR data will be compared to the WVR data to determine the cause of differences measured by the two systems. Gain instability currently limits the BWG TPR resolution. Techniques to measure and correct for gain change include the use of a signal power adding radiometer (SPAR). These techniques will be tested and analyzed to determine the ultimate sensitivity of the BWG antenna's TPR.

DELIVERABLES:
Periodic monthly progress reports.
TDA Progress Report on Atmospheric Noise Statistics (01 Sept 1997)
TDA Progress Report on SURFSAT-1 Data Analysis (Draft) 01 Sept. 1998
TDA Progress Report on MGS/KaBLE-II 01 Sept. 1998

	Prior Year	FY98	FY99	FY00	FY01	Total at Completion
Funding ($K)		152	148			300
Workforce (WY)		1	0.8			1.8
Co-funding ($K)						0
Projected Savings ($K)						0